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PREPRINT

DESIGN AND ANALYSIS OF ALTERNATIVE HIGH HEAT FLUX SOURCES FOR MATERIALS FIRE TESTING

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14. ABSTRACT
The majority of aircraft crash accidents involve ignition of the fuselage due to a burning external jet fuel fire. Because of this, occupant fatalities become heavily reliant upon the aircraft body remaining intact as exterior fire impinges upon it. To increase survivability, the Federal Aviation Administration (FAA) has developed a medium-scale laboratory test to analyze the burnthrough resistance of aircraft skin components using an impinging jet flame from an oil burner to simulate a real world fire condition. Over the years, the procedure has been forcibly refined due to inconsistent results among participating laboratories for instabilities in the jet flame. Although not an FAA testing goal, the test procedure also makes analysis of material off-gasses difficult due to comingling of both the oil burner and aircraft skin combustion flames. Since aircraft construction has transitioned largely to composite materials in recent years, an understanding of burnthrough resistance and fire behavior for these new materials has not been well documented in the open literature. In response, the Air Force Research Laboratory's (AFRL) Fire Research Group (RXQD) is developing high heat flux burner technology to replace the FAA oil burner to provide easier set-up, greater consistency, and simplicity in analyzing results for the pyrolysis of advanced composite materials. The overall objective is to use computational tools to design and analyze the performance of a plasma air torch and infrared emitter bank relying on core convective and radiant heat transfer technology, respectively. Successful validation of these models will lead to the development of computational tools that will help predict the onset of pyrolysis under multiple heat stress configurations. Successful experimental validation of these models will ultimately help develop safer, advanced materials for future deployable airborne and ground vehicles.

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CFD, materials fire characterization, FAA burnthrough testing, plasma air torch, short-wave infrared, composite testing, oxygen consumptoin calorimetry; ANSYS fluent; radiation modeling

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Design and Analysis of Alternative High Heat Flux Sources for Materials Fire Testing

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ABSTRACT

A study of survivable aircraft accidents followed by fire showed that the number of casualties could be significantly reduced by fire hardening the fuselage[1]. Because of this, occupant fatalities become heavily reliant upon the aircraft body remaining intact as exterior fire impinges upon it. To increase survivability, the Federal Aviation Administration (FAA) has developed a medium-scale laboratory test to analyze the burnthrough resistance of aircraft skin components using an impinging high heat flux (HHF) ($\approx$ 180 kW/m^2) jet fuel flame from an oil burner to simulate conditions observed in post-crash aviation fires (Figure 1)[2].

The latest generation of military and commercial aircraft is constructed with large quantities of carbon fiber composites. In particular the fuselage and wing skin and structural members are now routinely constructed entirely from carbon/BMI or carbon/Epoxy composites. From a fire protection point of view, this is a substantial difference from the traditional aluminum skin construction. This major change in construction materials has produced a need for improvements in HHF testing capabilities. The leading test for determining ignitability and heat release rate is the cone calorimeter[5]. This method applies heat flux loads from 25 to 100 kW/m^2. During earlier work with the FAA burn through apparatus, the Air Force Research Laboratory Fire Research Group (AFRL/RXQD) determined that the apparatus was not adequate for evaluation of carbon/polymer fuselage skins because of the overwhelming flame which often concealed skin ignition. AFRL/RXQD has begun development on a HHF burnthrough test method to replace the FAA oil burner to provide easier set-up, greater consistency, and simplicity in analyzing results for the pyrolysis of advanced composite materials.

An extensive review of technologies for generating suitable high heat fluxes resulted in the identification of two alternative technologies for generating the fluxes required, the infrared emitter bank, and the plasma air torch. The scope of this effort is to design and analyze two unique applications based upon their core convective and radiant mechanisms of heat transfer, a plasma air torch and infrared emitter bank, respectively. A convective as well as radiant heat transfer solution was selected on the basis of re-creating the primary heat transfer principles associated with an impinging jet flame.

The computational fluid dynamic (CFD) software package ANSYS Fluent® [9] was used to model heat transfer and flow physics for both heater simulations. Radiant heat transfer is calculated via the discrete ordinate (DO) model by solving for radiant intensity in a similar manner to the rest of the transport equations over a number of resolved spatial directions.

Based on the CFD models, the total surface heat flux at the sample is 240 kW/m^2 and approximately 220 kW/m^2 for the air torch and IR bank, respectively. The variation of the heat flux over the 10 cm sample area is in the range of 1 to 4%. The plasma air torch showed heavy expected dependency on convection heat transfer with only 0.3% being due to radiation in the presence of the refractory alumina nozzle. Convective heat transfer from the IR emitter bank to the ignition sample surface is nearly negligible. Overall heat transfer for both sources are heavily dependent upon material properties, thus accurate data on parameters such as thermal conductivity, specific heat, radiation absorption coefficient, refraction index, and specular vs. diffuse surfaces are critical in calculating accurate solutions.

The near equivalency of the model heat flux computations indicates that both sources can produce the heat flux over a sample area equivalent to that of the FAA burn through test. Since construction of the full scale apparatus will require substantial investment in equipment and infrastructure, the AFRL/RXQD management has funded construction of two small scale prototypes which will permit evaluation of 10 x 10 cm cone calorimeter sized samples. Using these two complimentary techniques, future studies will be aimed at determining the relative impacts of radiative and conductive heat transfer in the propagation of pool fire damage in the post crash pool fire regime. Finally, an understanding of the physical models learned here will then be applied to aid materials fire characterization in full-scale crash fire scenarios.

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INTRODUCTION

A study of survivable aircraft accidents followed by fire showed that the number of casualties could be significantly reduced by fire hardening the fuselage[1]. Because of this, occupant fatalities become heavily reliant upon the aircraft body remaining intact as exterior fire impinges upon it. To increase survivability, the Federal Aviation Administration (FAA) has developed a medium-scale laboratory test to analyze the burnthrough resistance of aircraft skin components using an impinging high heat flux (HHF) (≈ 180 kW/m^2) jet fuel flame from an oil burner to simulate conditions observed in post-crash aviation fires (Figure 1)[2]. Recently the procedure has been significantly revised to avoid non-uniform, inconsistent results among participating laboratories and lack of parts for the original apparatus.[3]

Figure 1. The medium-scale burn through test apparatus currently employed by the FAA.[3]

The latest generation of military and commercial aircraft is constructed with large quantities of carbon fiber composites. In particular the fuselage and wing skin and structural members are now routinely constructed entirely from carbon/BMI or carbon/Epoxy composites. From a fire protection point of view, this is a substantial difference from the traditional aluminum skin construction. This major change in construction materials has produced a need for improvements in HHF testing capabilities. The leading test for determining ignitability and heat release rate is the cone calorimeter[5]. This method applies heat flux loads from 25 to 100 kW/m^2. During earlier work with the FAA burn through apparatus, the Air Force Research Laboratory Fire Research Group (AFRL/RXQD) determined that the apparatus was not adequate for evaluation of carbon/polymer fuselage skins because of the overwhelming flame which often concealed skin ignition. Consequently, AFRL/RXQD has begun development on a HHF burnthrough test method to replace the FAA oil burner to provide easier set-up, greater consistency, and simplicity in analyzing results for the pyrolysis of advanced composite materials. The overall objective is to analyze composite fuselage ignition behavior under different heat transfer loading mechanisms, with plans to better define the fire protection needs of current and next generation aircraft coming into service.

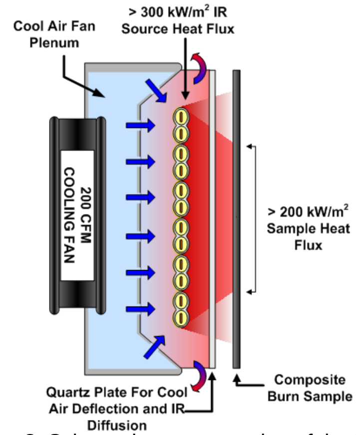

Figure 2. Schematic representation of the IR Emitter Bank.

An extensive review of technologies for generating suitable high heat fluxes resulted in the identification of two alternative technologies for generating the fluxes required. The Infrared Emitter Bank[6], Figure 2, follows the traditional fire property evaluation radiant heat approach with specialized gold reflectors to enhance heat transfer in the short-wave infrared wavelength regime. The Plasma Air Torch[7], Figure 3, is capable of jet exit temperatures in excess of 1575 K. The system is driven by an infinitely adjustable blower feeding air to an insulated refractory alumina/ resistance element heat exchanger matrix where incoming air is excited to a plasma state causing approximately 1% of the air to dissociate. This air dissociation increases the fluid's ability to transfer heat in greater excess compared to standard air heating methods.[8] Exit flow temperatures are a primary function of fluid residence time within torch chamber walls.

The scope of this effort is to design and analyze two unique applications based upon their core convective and radiant mechanisms of heat transfer, a plasma air torch and infrared emitter bank, respectively. A convective as well as radiant heat transfer solution was selected on the basis of re-creating the primary heat transfer principles associated with an impinging jet flame.

Figure 3. Plasma Air Torch.[7]

MODELING APPROACH

The computational fluid dynamic (CFD) software package ANSYS Fluent® [9] was used to model heat transfer and flow physics for both heater simulations. Radiant heat transfer is calculated via the discrete ordinate (DO) model by solving for radiant intensity in a similar manner to the rest of the transport equations over a number of resolved spatial directions.

RESULTS AND CONCLUSIONS

Figure 4 shows the high fluid temperature impinging on the sample surface reminiscent of the flame impingement produced in the FAA test apparatus. The IR emitter bank showed almost pure radiant energy at the sample surface, Figure 5.

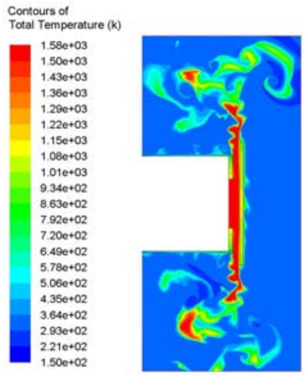

Figure 4. Plasma air torch contours of fluid total temperature.

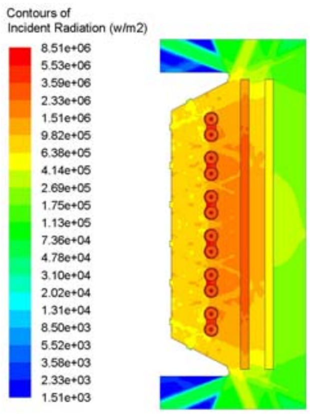

Figure 5. IR emitter bank contours of incident radiation.

Figure 6 presents the numerical results from the CFD models. Total surface heat flux at the sample is 240 kW/m^2 and approximately 225 kW/m^2 for the air torch and IR bank, respectively. The variation of the heat flux over the 10 cm sample area is in the range of 1 to 4%. The plasma air torch showed heavy expected dependency on convection heat transfer with only 0.3% being due to radiation in the presence of the refractory alumina nozzle. Convective heat transfer from the IR emitter bank to the ignition sample surface is nearly negligible.

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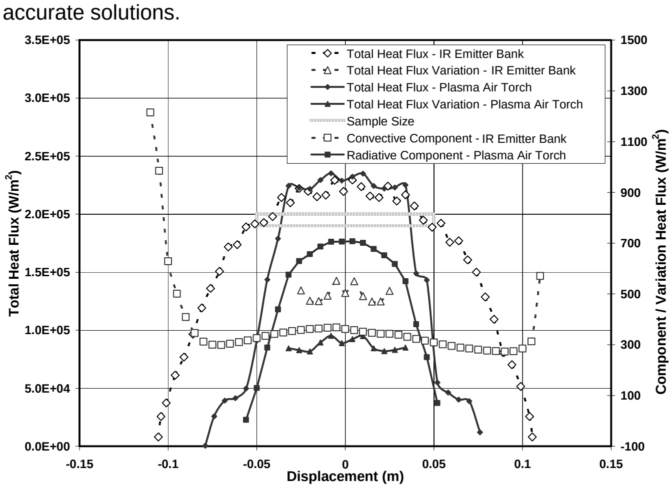

Figure 6. Calculated heat fluxes at sample based on CFD models.

FUTURE WORK

The near equivalency of the model heat flux computations indicates that both sources can produce the heat flux over a sample area equivalent to that of the FAA burn through test. Since construction of the full scale apparatus will require substantial investment in equipment and infrastructure, the AFRL/RXQD management has funded construction of two small scale prototypes which will permit evaluation of 10 x 10 cm cone calorimeter sized samples.

Using these two complimentary techniques, future studies will be aimed at determining the relative impacts of radiative and conductive heat transfer in the propagation of pool fire damage in the post crash pool fire regime.

Finally, an understanding of the physical models learned here will then be applied to aid materials fire characterization in full-scale crash fire scenarios.

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REFERENCES

1. Cherry, R and Warren, K., Fuselage Burnthrough Protection For Increased Postcrash Occupant Survivability: Safety Benefit Analysis Based On Past Accidents, DOT/FAA/AR-99/57, September 1999, National Technical Information Service (NTIS), Springfield, Virginia 22161. Available at: http://www.tc.faa.gov/its/worldpac/techrpt/ar99–57.pdf.
2 14 **CFR** 25 Appendix F, *Part VII—Test Method To Determine the Burnthrough Resistance of Thermal/Acoustic Insulation Materials*
3. Ochs, R., Burnthrough Test Method for Aircraft Thermal/Acoustic Insulation: NexGen Burner Update, International Aircraft Materials Fire Test Working Group, June 2007, http://www.fire.tc.faa.gov/ppt/materials/June07Meeting/ochs-0607-NexGenBurnerUpdate.ppt.
4. Yarlagadda, S., Chatterjee, A., Gillespie, J. W., Jr, Kiel, J. C., McGraw, D, and Dierdorf, D. S., Post-Fire Damage Assessment of a Composite Wingbox, Proceedings of the SAMPE 2004 Symposium, May 16-20, 2004, Long Beach, CA.
5. ASTM E13504-04a Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. Book of Standards 04.07
6. The IR Emitter Bank was designed and built by Heraeus Noblelight, 2150 Northmont Parkway, Duluth GA 30096 USA
7. The Plasma Air Torch was designed and built by MHI (Micropyretics Heaters International Inc.), 750 Redna Terrace, Cincinnati, OH 45215, USA, **US Patent** 6,816,671 B1, 11/1/2004.
8. Rajamani, V., Anand, R., Reddy, G. S., Sekhar, J., Jog, M. A., Enhancement of Heat Transfer Due to Plasma Flow in Material Processing Applications, IMECE2005-79782, 2005 ASME International Mechanical Engineering Congress and Exposition, November 2005, Orlando, Florida USA.
9. Fluent Inc., 10 Cavendish Court, Lebanon, NH 03766.